EROSION FEATURES IN MEDITERRANEAN LANDSCAPES ASSESSED BY FALLOUT ^{137}Cs

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ABSTRACT

In this work, the ^{137}Cs technique is applied as an approach to examine the environmental impact of erosion and sedimentation on soil and water sustainability in Mediterranean landscapes of NE Spain. This region has a large diversity from the semiarid steppe in the centre of the Ebro valley to alpine mountains in the Pyrenees Range. The role played by land cover and cultivation on soil loss is assessed on representative slopes of the phyisographic variety in central Ebro basin by using the radiometric technique.These case-studies evidence the fragility of Mediterranean agrosystems and the need for establishing land management practices aimed to landscape conservation as in this environment soil essentially constitutes a non-renewable resource.

EVALUACIÓN DE LAS CARACTERÍSTICAS DE LA EROSIÓN EN ZONAS MEDITERRÁNEAS MEDIANTE EL CESIO 137 PRECIPITADO

RESUMEN

En este trabajo se aplica la técnica del Cs-137 para evaluar el impacto medioambiental de la erosión y sedimentación en la sostenibilidad de los suelos y el agua de la zona mediterránea del nordeste de España. Esta región tiene una gran diversidad de estepas semiáridas en el centro del valle del Ebro hasta las montañas alpinas de los Pirineos. La importancia de la cubierta del terreno y el cultivo en la pérdida de los suelos se evalúa en las pendientes representativas de la variedad físicogeográfica de la cuenca del Ebro central mediante la técnica radiométrica. Los estudios de caso evidencian la fragilidad de los agrosistemas mediterráneos y la necesidad de establecer prácticas de gestión de las tierras para la conservación de los terrenos, ya que en este medio el suelo constituye un recurso no renovable.

Key words: cesium 137; soil conservation; erosion; sediments; ambient temperature; mountains; landscaping; environmental impacts

INTRODUCTION

Some regions in Spain, as Aragón in the middle Ebro basin, are suffering important soil losses affecting productivity of rainfed agriculture. The extent of this problem has motivated much concern about the future of our fragile agrosystems. The need for implementing soil conservation measures in a context of landscape and soil conservation require first of all to know the features and magnitude of soil movement. To this purpose, we apply the ^{137}Cs radiometric technique as sediment tracer. This radioisotope has been widely applied in many different environments around the world [1-3] and it has proved to be a reliable method for describing these processes in the Ebro basin [4,5].

Soil losses are influenced by various factors among which climate, soil types, slope orientation, vegetation cover and land use are the more relevant. The role played by these factors depends on the physiographic characteristics of the environments and have derived implications for infiltration, runoff and consequently affect the erosion process [6].
In the central part of the Ebro basin, a climatic gradient exist from the valley centre with semiarid climate (300 mm of annual rainfall) towards the temperate Pyrenean middle mountains (>800 mm).
In this paper we analyse the erosion pattern in two very contrasting landscapes by fallout ^{137}Cs. One of the study sites is located in a semiarid environment near Ejea city and the other lies near

Jaca in a temperate environment of the Pyrenean middle mountains. Our aim is to assess the role of land cover and cultivation on soil loss in this two environments, as an approach to suggest guidelines for soil sustainability.

MATERIALS AND METHODS

The semiarid and temperate study areas present different physiographic characteristics and they are located in the middle Ebro basin (figure 1). Their main differences are climate, soil types and land cover. In the semiarid Ejea site, located in the central part of the Ebro valley, marls and limestones compose a landscape of high Tertiary plateaux dissected by a fluvial network, flooding towards the Ebro river. On the slopes, stony soils are mainly Regosols covered partially by shrubs. Cultivated fields occupy flat or gentle slope areas of Cambisols and Calcisols. The mean annual rainfall is below 400 mm, and occurrence of short and intense storm events increase the erosion risk. In this area agrosystems are very fragile.

The temperate site around Jaca, is located in the central part of the Pyrenees. Materials in the area are sandstones and marls that form a mountaineous landscape. Cambisols and Kastanozems predominate on slopes covered by dense pine wood on the North facing slopes and *Quercus gr. faginea* forest and shrubs on the sunny ones. Soils are more fertile, deeper and better developed than in the semiarid site. Annual rainfall is around 1000 mm. Land use is mainly as meadows as well as for cereal cultivation.

Fallout ^{137}Cs is applied as tracer of sediment movement. On selected sites of both semiarid and temperate environments, the soil loss or gain is identified by comparing the radioisotope levels over the site with the total fall-out to the site. Whole core samples were collected on a grid pattern of sampling points that were separated around 25 m each, by using an automatic core driller. Along slope transects, samples were sectioned at 5 cm depth increments to examine the ^{137}Cs depth profile in order to identify samples as stable, eroding or aggrading points. The depth of sampling was between 30 and 40 cm and retained the entire ^{137}Cs profile.

The methodology for natural gamma-emitting radionuclides analysis is described in detail in [7]. The samples of the fraction under 2 mm are measured using gamma spectrometry in order to obtain the concentration of ^{137}Cs (mBq.g^{-1}) from the number of counts under its photopeak of 662 keV. ^{137}Cs is expressed per unit area in mBq.cm^{-2}. Measurements of radionuclides activities in soil samples were undertaken by using a high resolution, low background, hyperpure coaxial gamma-ray detector (EG&G ORTEC HPGe) coupled to an ORTEC amplifier and multichannel analyser. The detector is surrounded with shielding material to reduce the background counting rate.

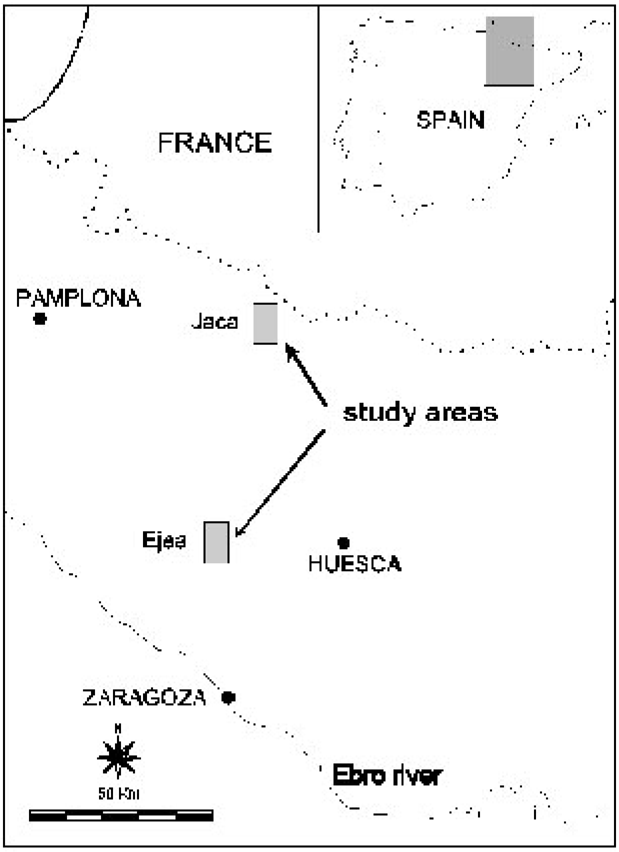

Figure 1.Geographical situation of the studied sites.

^{137}Cs PROFILES IN THE SEMIARID AND TEMPERATE ENVIRONMENTS

The average ^{137}Cs inventory for the Ejea semiarid area is around 190 (±20) mBq.cm^{-2}, whilst in the temperate environment, the input fallout is around 400 (±25) mBq.cm^{-2}. At each site, inventories were calculated from 9 soil samples collected at stable sites. As can be seen in figure 2, at stable sites the ^{137}Cs profile shows the typical pattern of accumulation in the upper 10 cm and below this layer it shows a sharp exponential decrease with depth. At the semiarid site, the ^{137}Cs concentration at surface layers ranges between 20 to 27 mBq.g^{-1}, and between 10 to 15 mBq.g^{-1} at 5-10 cm depth. Below 10 cm, values are around 5 mBq.g^{-1} and decrease sharply to undetectable levels at depths higher than 30 cm. At the temperate site, the ^{137}Cs concentration at 0-5 cm depth ranges between 30 to 37 mBq.g^{-1}, and between 20 to 25 mBq.g^{-1} at 5-10 cm depth. Below 10 cm, values are around 10 mBq.g^{-1} and also decrease sharply to undetectable levels at depths higher than 30 cm. Therefore, in average, concentrations are more than 50% higher in the temperate than in the semiarid environment.

Along the slope of both environments a variety of ^{137}Cs profiles are found. Figure 3 presents a selection of the most representative profiles: stable, eroding, aggrading and ploughed profiles, where the radioisotope is evenly distributed along the soil profile. In general, the above mentioned sequence is mostly found respectively at hill top, mid slope and bottom slope locations. Nevertheless, this pattern can be modified by several factors, as the presence of rock outcrops, stones or shrubs after a bare soil surface that may favour the accumulation of detached particles. Therefore aggrading profiles can be found at locations such as mid slope where normally eroding profiles would be expected due to the common lack of vegetation that promote erosion by runoff.

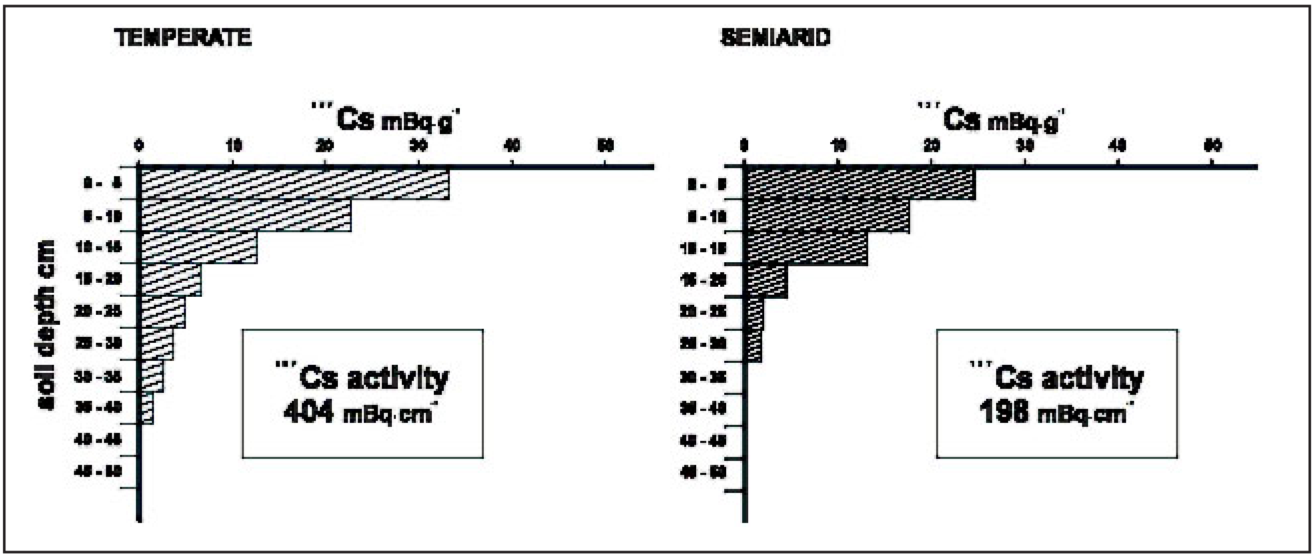

Figure 2. ^{137}Cs reference inventories for the semiarid and temperate environments.

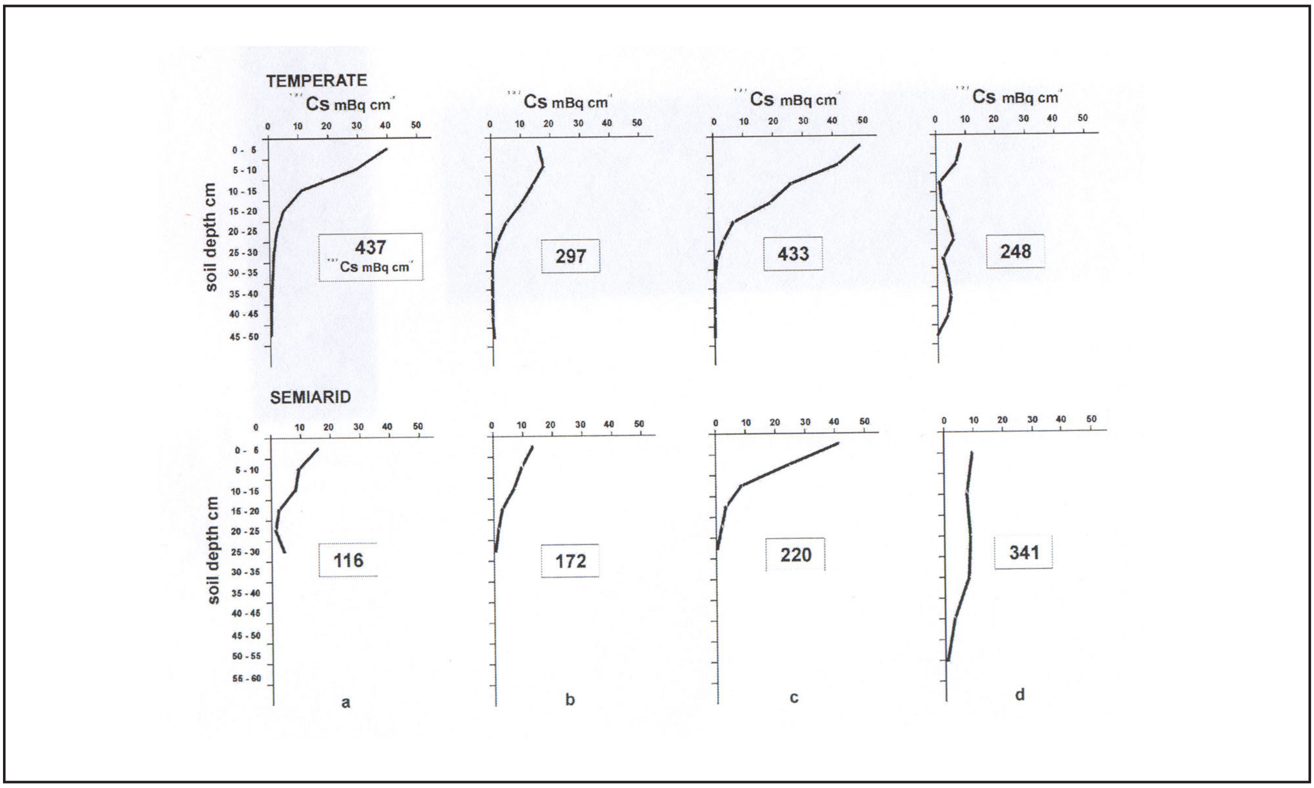

Figure 3. Typical depth profiles along slopes in the semiarid and temperate environments.

THE ROLE OF LAND USE AND LAND COVER ON SOIL MOVEMENT

The effect of land use on soil movement has been assessed in both environments, by measuring the ^{137}Cs activities under two different land uses: cultivated and uncultivated, i.e. under natural vegetation cover. For each land use, two sampling sites separated by a distance no longer than 1 km were selected. In each site, samples were collected on a grid pattern. In the semiarid environment, 9 samples separated around 25 m were taken in each site totalling 36 soil samples. In the temperate environment, the two cultivated sites had 15 samples, 8 and 7 respectively, and 12 samples (6 + 6) were taken at the two uncultivated sites. Table 1 shows some characteristics of the study sites.

At the semiarid environment, due to limiting edaphic and climatic conditions most cultivated soils are on flat top surfaces on plateaux or hills, valley floors, or on gentle slopes. The cultivated sites selected for this study are quite level (2% and 5% slope) and they are planted with cereals (barley) grown one year in two. At the uncultivated sites on shrubland slopes (25% and 30% slope), almost half of its surface is naturally vegetated with small shrubs and grasses, but there are also patches with no vegetation as well as others covered only with stones.

Data presented in table 2, show that at both cultivated sites, the average ^{137}Cs activity deviates from the reference inventory for the area. At the 2% slope site, activity is 16% lower than the inventory. At the 5% slope site average activity is 14% higher than the inventory and the standard deviation (sd) is very high (134.4 mBq. cm^{-2}) suggesting that there is an important redistribution of sediments at this site that could may be due to its higher slope compared with the former almost level site. The uncultivated sites have also average activity values that differ from the reference inventory, the 30% slope site has an average activity 10% higher than the inventory while the 25% slope site has activity values that in average are 17% lower than the reference inventory.

At the uncultivated slope, the less sloping site has the higher variability suggesting that its higher redistribution of sediments could be related to the lower percentage of vegetation covering the soil surface at this site which is around 10% lower than at the former site. Therefore, the vegetation cover would counteract the effect of the higher slope in increasing soil movement and consequently soil erosion would be more intense in the less vegetated site.

In the temperate environment, because its mountaineous landscape, cultivated fields occupy

Table 1. Edaphic and physiographic characteristics of the studied sites

		slope %	vegetation cover %	soil type	pH	OM%	CO_3 %
semiarid	cultivated	12	-	cambisol	8.7	2.5	25
		5	-	calcisol	8.7	1.3	55
	uncultivated	30	50	regosol	8.7	3.0	39
		25	40	regosol	8.8	3.1	42
temperate	cultivated	12	-	cambisol	8.0	2.6	27
		15	-	cambisol	8.8	2.7	35
	uncultivated	24	70	kastanozem	8.3	3.9	31
		26	70	kastanozem	8.4	3.5	40

Table 2. Least square means of the caesium137 activity and standard deviation in the studied sites of the semiarid and temperate environments. (Different letters indicate statistically significant differences)

		n	^{137}Cs mBq.cm^{-2}	
			mean	sd
semiarid	cultivated	9	160.5 a	36.2
		9	215.9 a	134.4
	uncultivated	9	209.9 a	48.2
		9	157.0 a	60.6
temperate	cultivated	8	499.4 a	84.9
		7	333.6 b	86.5
	uncultivated	6	387.2 b	58.2
		6	385.2 b	88.1

areas, generally valley bottoms, with slopes higher than in the semiarid environment. In the 12% slope cultivated site, average ^{137}Cs activity is 25% higher than the inventory, while at the 15% slope average activity is 17% lower than the inventory. Both sites have high and very similar sd values, suggesting that redistribution of sediments is also quite intense and opposite because aggradation predominates in the former site and erosion in the latter. Because both sites have very similar slopes, although it is slightly higher in the most eroded site, this small difference in slope value, does not seems to be enough to justify the dissimilarity in soil movement patterns. An explanation could be due to differences in topography or land management in the studied sites.

As expected, the ANOVA test indicated that statistically significant differences in mean radioactivities exist between the semiarid and temperate environments.

The percentages of deviation of ^{137}Cs activities in comparison with the reference inventories for the semiarid and temperate environments are shown for each site in figure 4. In the semiarid environment, at the 2% slope cultivated site, two sampling points are stable, six are eroding points of which in two of them erosion is not very intense, and sediments accumulate only at one sampling point. The higher slope seems to affect soil movement as there is a more intense soil redistribution at the 5% slope cultivated site, in which only two are stable points, four are aggrading points and three are eroding points.

At the uncultivated sites, the 30% slope is a quite stable site, the ^{137}Cs activity is comparable to the reference inventory at six sampling points, two are aggrading points and slight erosion occurs at just one sampling point. The situation is different at the 25% slope uncultivated site, where erosion predominates as depletion is clearly registered in six sampling points, only two are stable points and some sediment accumulation is registered at just one sampling point. In a similar environment nearby [8] found that erosion rates on cultivated land on gentle slopes were five times higher than in sloping uncultivated land.

In the temperate environment, although sites have very similar slope values, both cultivated sites differ markedly in their ^{137}Cs activities. At the 12% slope site, only two sampling points have values similar to the reference inventory and the remaining six are aggrading points. Conversely at the 15% slope site, erosion predominates as only three points are close to the reference inventory and the remaining five are eroding points. Therefore apart from differences in tillage or other land management practices, the reason for this dissimilarity could may be due to their respective topographic positions within the landscape, because although both are at bottom slope positions, the 12% slope site is located along the maximum slope line, and this could mean that higher load of sediments are mobilized along this line from up-slope, and as a result aggradation exceeds erosion at this site in comparison with the 15% slope site that has a lateral position along the main slope line.

In the temperate uncultivated sites, the distribution of ^{137}Cs activities is very similar and, in average, their point values, only deviate slightly (- 3%) from the reference inventory. Although erosion slightly predominates in both sites, the remaining sampling points are half each stable and aggrading respectively.

It can be said, in general, that the larger variability in ^{137}Cs activities is found at the cultivated sites of both environments, the highest being at the 5% slope in the semiarid environments, but it is also found that when cultivation is done on almost level surfaces soil movement is not very important. These findings strengthen previous results that indicated that cultivation in semiarid environments was a main factor causing soil erosion [9] and also agree with other authors that disclosed the key role of tillage on soil movement and redistribution across cultivated fields [10,11].

At the uncultivated sites with higher slopes in both environments compared with the cultivated sites, the

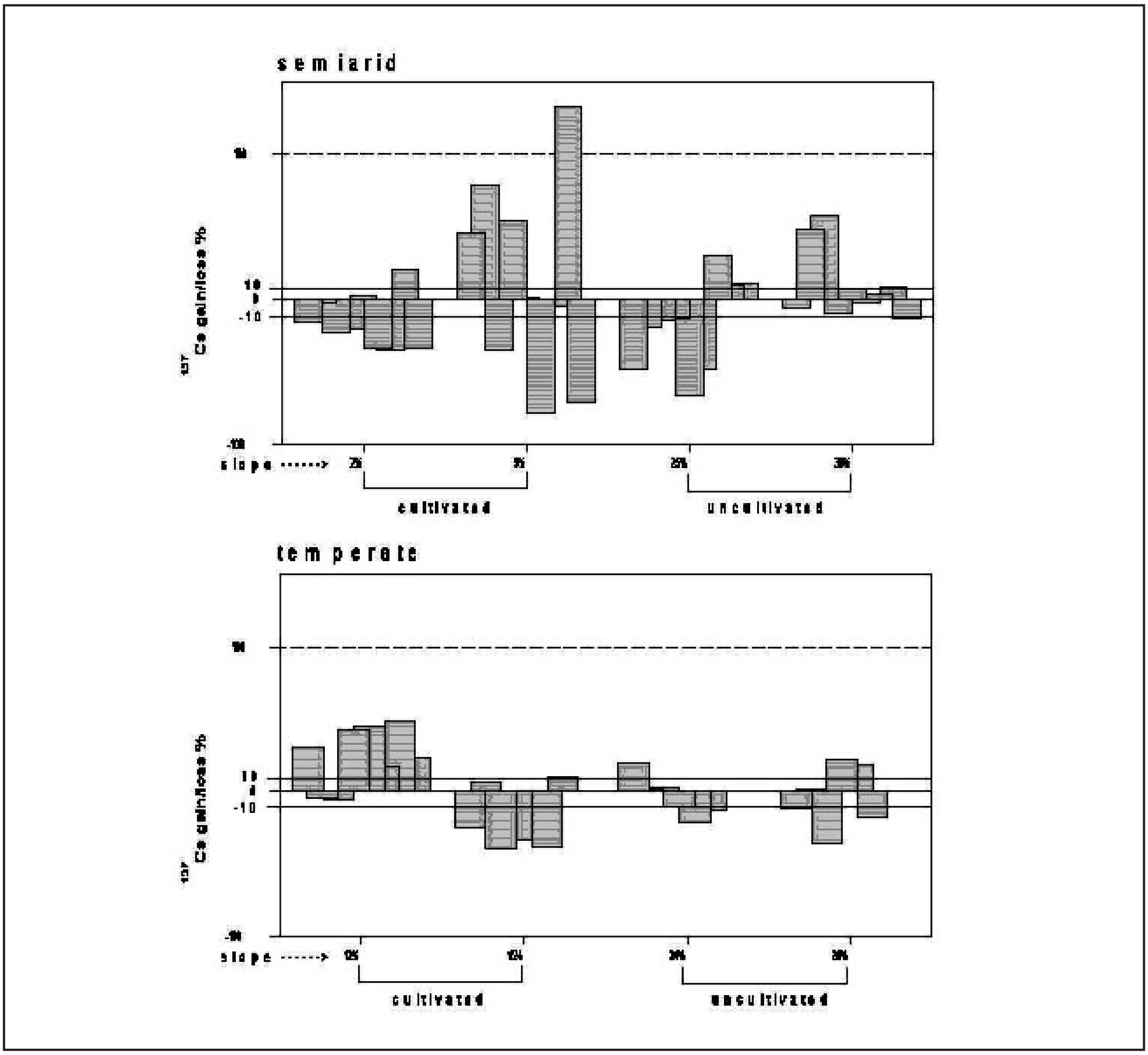

Figure 4. Percentages of ^{137}Cs deviation from the input fallout (gain or loss) in the cultivated and uncultivated soils of the semiarid and temperate environments.

land cover of shrubs protects the soil surface and counteracts the effect of the slope gradient. In average, percentage deviations from the ^{137}Cs inventories are lower in the temperate environment as could be expected because of its higher percentage of surface covered by vegetation (>70% against <50% in the semiarid environment).

In comparison, the higher fragility of the semiarid environment is evidenced by the fact that even small differences in the percentage of surface covered by vegetation (less than 10%) can not compensate the lower slope and erosion is higher at the less sloping site. In spite, that soil redistribution is more intense in cultivated soils, also the uncultivated shrublands exhibit a large variation in radioactivities, indicating than in both environments almost all situations (stable, eroding or aggrading) can be found along short distances.

CONCLUSIONS

Fallout ^{137}Cs has been confirmed as a useful tracer of soil movement and served to assess the influence of land use and slope on soil redistribution, as well as to confirm the different erosion patterns found in uncultivated and cultivated fields of semiarid and temperate environments. Results from this study show the impact of land uses in semiarid and temperate Mediterranean environments. In both environments cultivation on sloping surfaces is a main factor causing erosion, consequently any attempt to reduce soil loss and off-site impacts should be focused on erosion control of the cultivated land. In the studied sites, it is found that the shrubs cover protects quite efficiently the soil surface from erosion.

Acknowledgements: This work was funded by CICYT throughout their research projects AMB93-0806 and RADIERO (REN2002-02702/GLO).

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